

INTERFEROMETRIC MOLECULAR LINE OBSERVATIONS OF W51

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This abstract presents observations of the HII region complex in W51 made with the Hat Creek millimeter interferometer. W51 is a region of massive star-formation approximately 7 kpc distant from the sun (cf. Bieging, *et.al.* 1975). This region has been extensively studied in both the infrared and submillimeter (Genzel, *et.al.* 1982, Jaffe, *et.al.* 1984, Jaffe, *et.al.* 1987) and the radio (Scott 1978, Genzel, *et.al.* 1982, Ho, *et.al.* 1983) as well as in maser transitions (Genzel and Downes 1977). These previous observations have revealed three regions of interest: (1) W51MAIN, a knot of bright maser emission near two compact HII regions W51e1 and W51e2 (Genzel and Downes 1977, Scott 1978). W51MAIN is also the peak of the 400 μm emission indicating that the bulk of the mass ($\approx 50,000 M_{\odot}$) is centered here (Jaffe, *et.al.* 1984). However, there is no 20 μm emission towards W51MAIN (Genzel, *et.al.* 1982) implying a large extinction in that direction. This is consistent with a dense molecular cloud shrouding the forming O and B stars. (2) W51IRS1 is a long curving structure seen at 20 μm and at 2 and 6 cm but not at 400 μm . (3) W51IRS2 (also known as W51NORTH) is another compact HII region slightly offset from an 8 μm and a 20 μm peak and a collection of H₂O masers (Genzel, *et.al.* 1982, Genzel and Downes 1977). In both W51MAIN and W51IRS2 there is hot (100 K) ammonia seen (Ho, *et.al.* 1983) and evidence for outflow activity (red- and blue-shifted masers, shock-excited H₂, and high-velocity wings of SiO (Genzel, *et.al.* 1981, Schneps, *et.al.* 1981, Beckwith and Zuckerman 1982, Downes, *et.al.* 1982).

These observations were made with 8 configurations of the three 6.1m antennas at the Hat Creek millimeter interferometer. The observations were made with a 512-channel digital correlator allowing simultaneous observations of the HCO⁺ $J = 1 \rightarrow 0$ transition, the SO 2₂ \rightarrow 1₁ transition, and the H¹³CN $J = 1 \rightarrow 0$ transition, all with $\approx 5'' \times 6''$ resolution. In addition, a 3.4mm continuum emission map was made from the channels with no molecular emission.

SO and H¹³CN Emission

Figure 1 shows maps of SO and H¹³CN emission towards W51. In each case the distribution of the emission consists of three point sources (emission peaks 1, 2, and 3), surrounded by weak, diffuse emission. These point sources coincide with extensive evidence for outflow activity: H₂O maser proper motions, quadrupole lines of H₂, and high-velocity line wings of SiO, as well as hot ($T > 100$ K) NH₃ emission (Ho, *et.al.* 1983, and references therein). The compactness of the SO emission in conjunction with the large extent of the emission from HCO⁺, a molecule requiring equally high densities to excite, implies that there is an SO abundance enhancement near these star-forming regions. Compact SO emission is also seen in association with Orion, W49, SgrB2, and G34.3+0.2 (Hat Creek results in preparation). Thus, this result seems to be universal to high-mass star-forming

regions with outflows, and it may be possible to use such small-scale SO emission as a signpost of outflow activity. In addition, a fourth H^{13}CN emission peak is detected $\approx 13''$ northwest of W51MAIN.

Continuum Map

Figure 2 shows the 3.4mm continuum map. W51 e1, e2, IRS1, and IRS2 are detected. The overall structure of the emission is very similar to that seen at 1.3cm (Ho, *et.al.* 1983). W51 e1 and e2 are unresolved, while IRS2 has a size $6''.7 \times 9''.7$ which deconvolves to $\approx 3'' \times 8''$. W51IRS1 also shows some evidence for the curving structure to the south seen at 6cm and $20\mu\text{m}$. A new source, not seen at 1.3cm, and therefore likely due to thermal dust, is detected. This source, labeled W51DUST, is coincident with the source H^{13}CN -4, and may constitute a region in very early stages of star formation.

HCO^+ Spectra

Figure 2 also shows spectra of HCO^+ towards the four main continuum sources, e2, e1, IRS1, and IRS2. All four spectra show red-shifted absorption, indicating the presence of infalling gas. These spectra are consistent with overall collapse of the W51 region towards the mass concentration at W51MAIN. This result is similar to that found by Welch, *et.al.* (1987) for W49. Thus these observations confirm that large O-B associations are formed by overall collapse of the molecular cloud.

The spectrum towards W51IRS1 shows both red-shifted *and blue-shifted* absorption. If the infall picture is correct then the detection of both red-shifted and blue-shifted absorption towards W51IRS1 suggests that it may be behind the collapsing sphere of material and thus the emission is absorbed by material in both directions of the infall.

Continuum Spectra : Evidence for Dust Emission at 3.4mm

Figure 3 contains a table of fluxes for the sources in W51, and shows the spectra plotted below. W51e2 is an ultracompact HII region closely associated with the maser emission W51MAIN. The long wavelength emission of this source is consistent with optically thick free-free emission with a turnover frequency of ≈ 23 GHz. If the source has a temperature of 10000 K, then the implied emission measure is $2 \times 10^9 \text{ cm}^{-6} \text{ pc}$, the size is $3 \times 10^{16} \text{ cm}$, the density is $5 \times 10^5 \text{ cm}^{-3}$. These all imply 8×10^{47} ionizing photons/sec, consistent with a single O9 star.

Extrapolating the 1.3cm free-free emission of 0.38 Jy to 3.4mm, one finds an excess of 0.9 Jy. This excess is due to dust. The 3.4mm excess plotted along with the peak fluxes of the lower resolution 1.2mm and $400\mu\text{m}$ maps, fit a power law of $\lambda^{-3.4 \pm 0.1}$, consistent with thermal dust with an emissivity $\epsilon \propto \lambda^{-1.4 \pm 0.1}$.

W51e1 shows an essentially flat spectrum from 6cm to 1.3cm, indicating that it is optically thin at these wavelengths. This is consistent with e1 being a more evolved region than e2. The 3.4mm flux of 0.39 Jy again shows an excess over the 1.3cm flux of 0.18 Jy.

The $400\mu\text{m}$, 1.2mm, 3.4mm, and 1.3cm fluxes, integrated over a region $\approx 40''$ in size, including W51 e2, e1, and DUST, are plotted as W51MAIN. Fitting the 3.4mm excess with

the shorter wavelength measurements gives an excellent fit to a power law of $\lambda^{-3.2 \pm 0.1}$. Thus, the dust around W51MAIN is in two components:

- 1) A point source concentrated within the ultracompact HII region e2 ($d < 2 \times 10^{16}$ cm).
- 2) Extended emission within $40''$ of W51MAIN, primarily in W51e1 and W51DUST.

W51IRS2 also shows a 3.4mm/1.3cm excess. The 3.4mm flux is 5.41 Jy and the 1.3cm flux is 3.34 Jy. The fit to the 3.4mm dust contribution, and the 1.2mm and $400\mu\text{m}$ integrated fluxes is $\lambda^{-3.1 \pm 0.1}$.

Conclusions

The conclusions are as follows:

- 1) SO and H^{13}CN emission are similar and coincide with outflow activity
- 2) HCO^+ spectra show evidence for overall collapse of the W51 cloud towards W51MAIN. W51IRS1 is behind this collapsing sphere.
- 3) A previously undetected continuum peak, W51DUST, coincides with the molecular peak H^{13}CN -4. This may be a region in the very early stages of star-formation.
- 4) Dust emission at 3.4mm reveals that about half the $400\mu\text{m}$ emission comes from the ultracompact HII region e2, and the rest from W51e1 and W51DUST. W51IRS2 also shows evidence for dust at 3.4mm.

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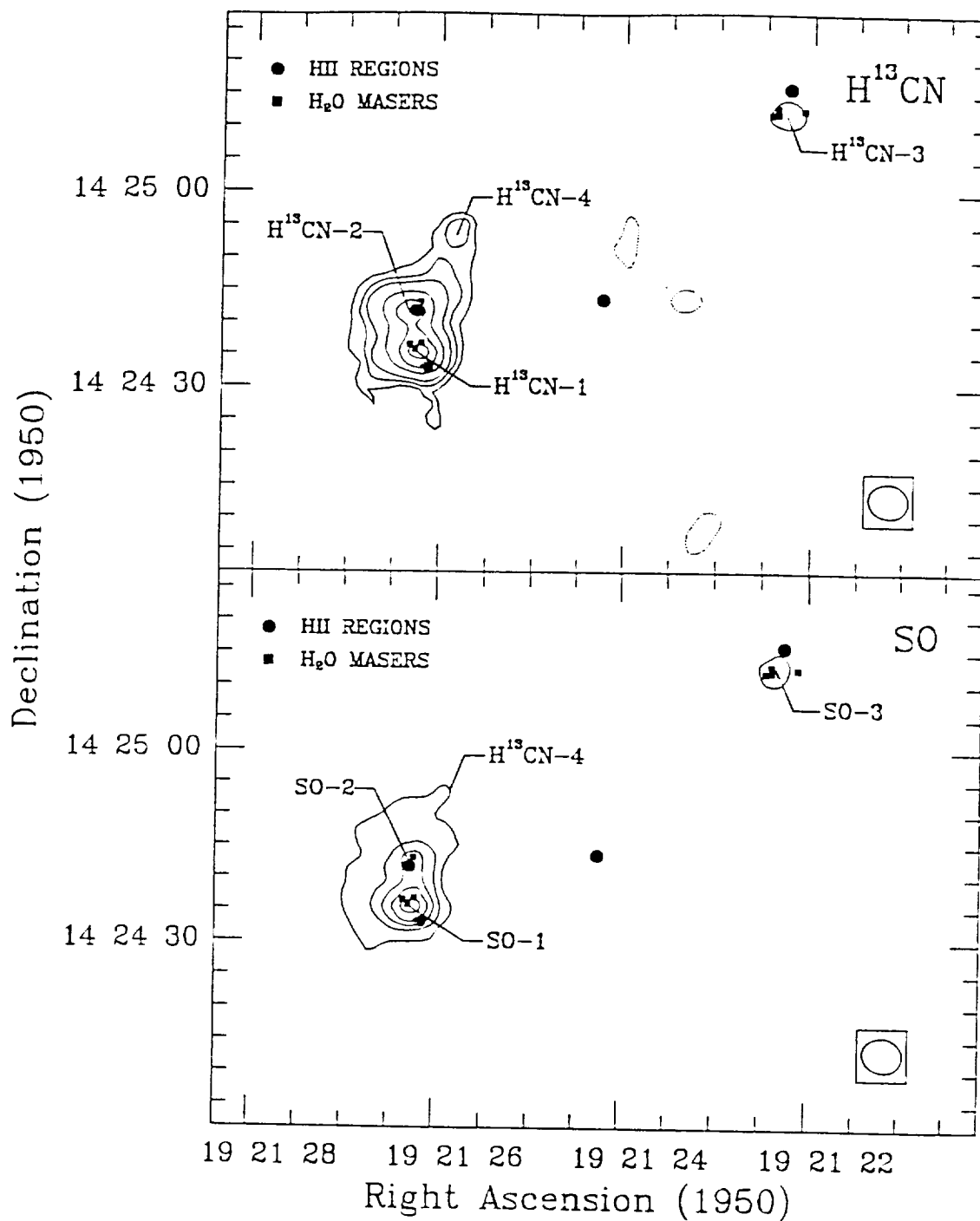


Figure 1

Top - $\text{H}^{13}\text{CN}(J=1 \rightarrow 0)$ emission from W51. Contour levels are $-.2, -.1, .1, .2, .3, .5, .7, .9$ of the peak flux of 7.7 K ($1\sigma = 0.3$ K).
 Bottom - $\text{SO}(2_2 \rightarrow 1_1)$ emission from W51. Contour levels are $-.1, .1, .3, .5, .7, .9$ of the peak flux of 6.1 K ($1\sigma = 0.3$ K).
 Peaks are marked by numbers 1, 2, 3, 4. Squares are HII regions, circles are prominent H_2O maser clusters. The beam is $6''.4 \times 5''.3$.

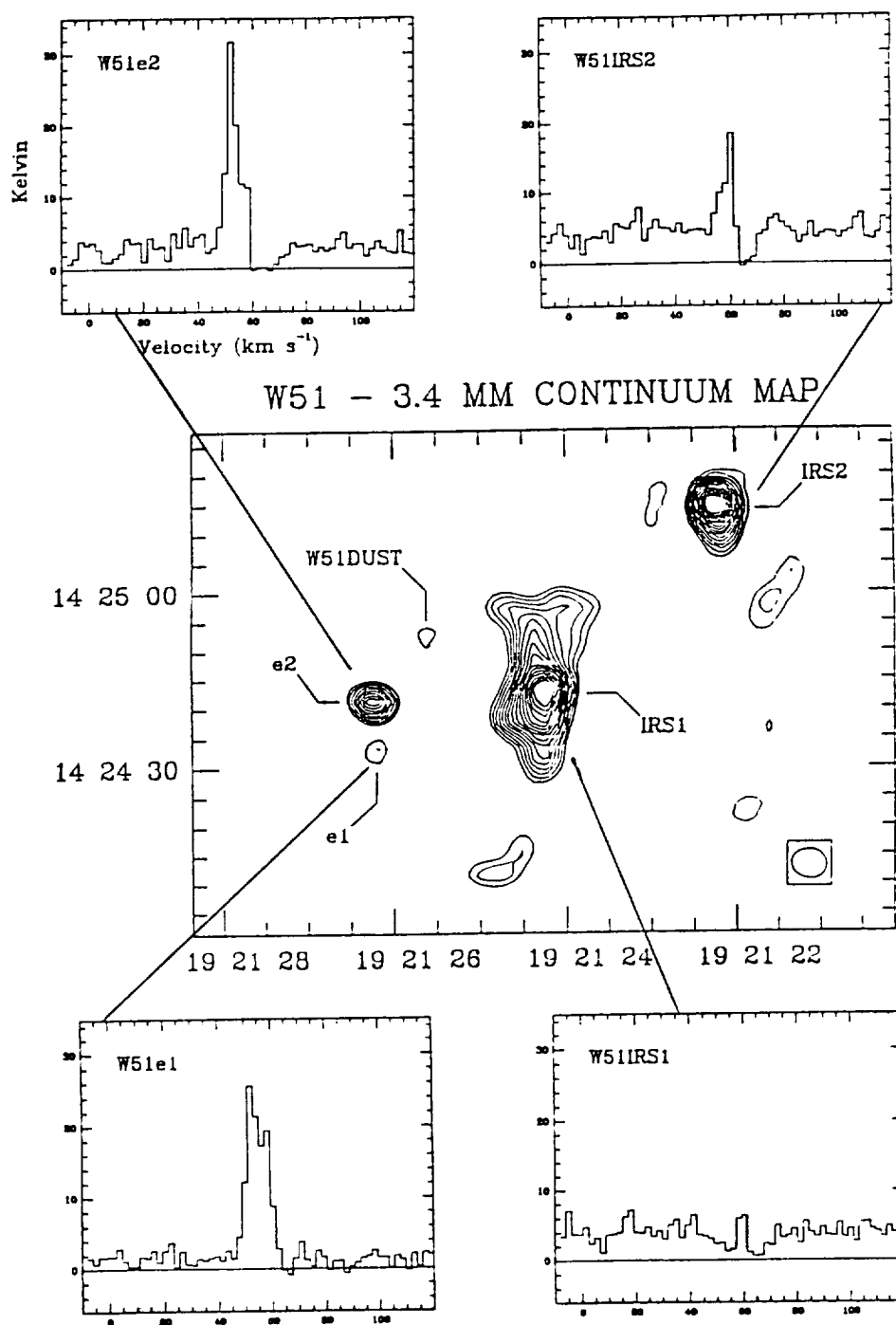


Figure 2

3.4 mm continuum map of W51. Contour levels are -5, -4, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19 times 0.060 Jy/beam (1σ). The four spectra are HCO⁺ (J=1→0) emission towards the four main continuum emission features. All four spectra show red-shifted absorption indicating the presence of infalling gas. The spectrum towards W51IRS1 shows both red- and blue-shifted absorption indicating that it is behind the infalling cloud.

Fluxes for W51^a

Source	6cm	2cm	1.3cm	3.4mm	3.4 ^(dust) mm	1.2mm	400 μ m	α^{dust}
W51e2	<0.02	0.15	0.38	1.23	0.90	26 ^b	1200 ^b	3.4 \pm 0.1
W51e1	0.14	0.19	0.18	0.39				
W51MAIN ^c			0.56	3.25	2.76	74	2500	3.2 \pm 0.1
W51IRS2 ^d			3.34	5.41	2.95	54	1800	3.1 \pm 0.1

W51 SPECTRA

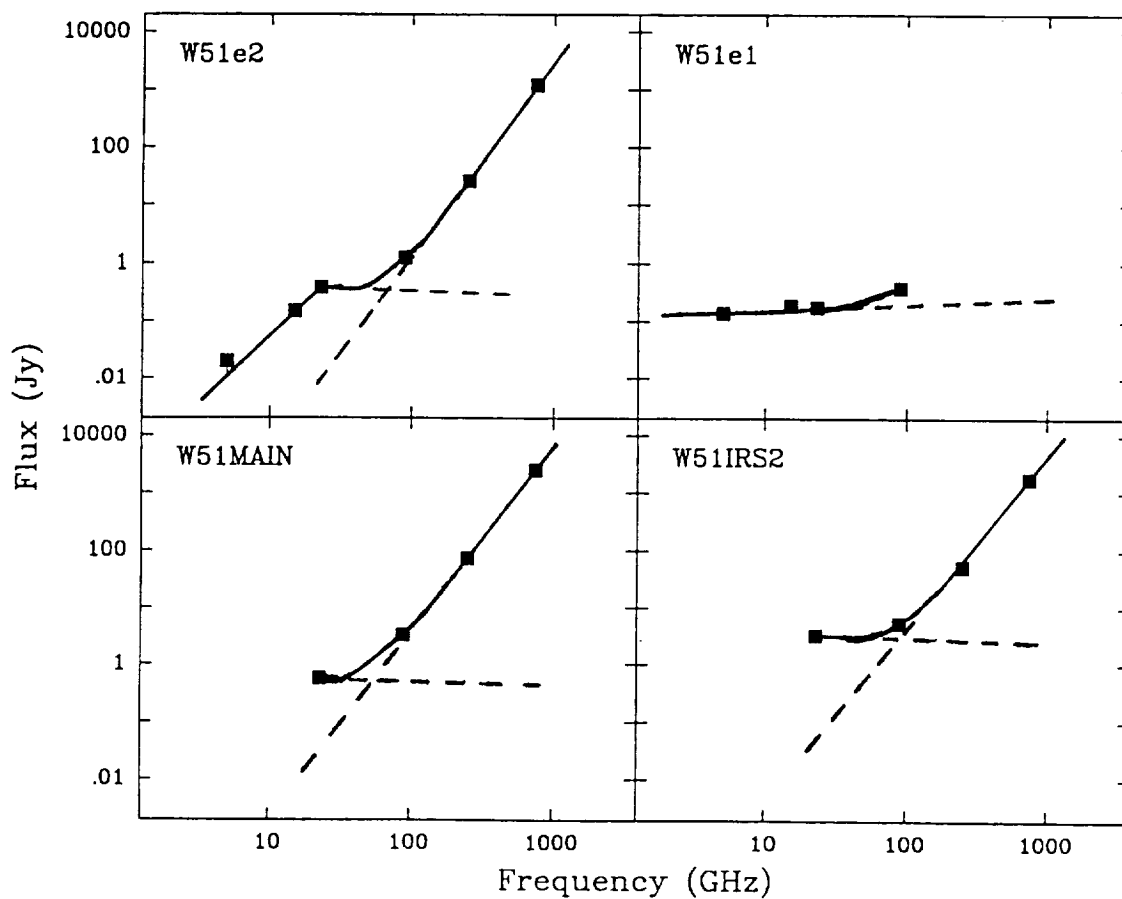


Figure 3

Spectra of W51 e2, e1, MAIN, and IRS2.

2.6 cm Scott (1978)
 1.3 cm Ho, et al (1983)
 3.4 mm This work
 1.2 mm Martin (1987)
 400 μ m Jaffe, et al (1984)

^aAll fluxes in Jy except as noted
^bPeak flux in Jy/beam
^cTotal flux from 40" area
^d1.3cm and 3.4mm are primary beam corrected